



**M2-F1 Under Tow**



**M2-F1 Glide Flight**

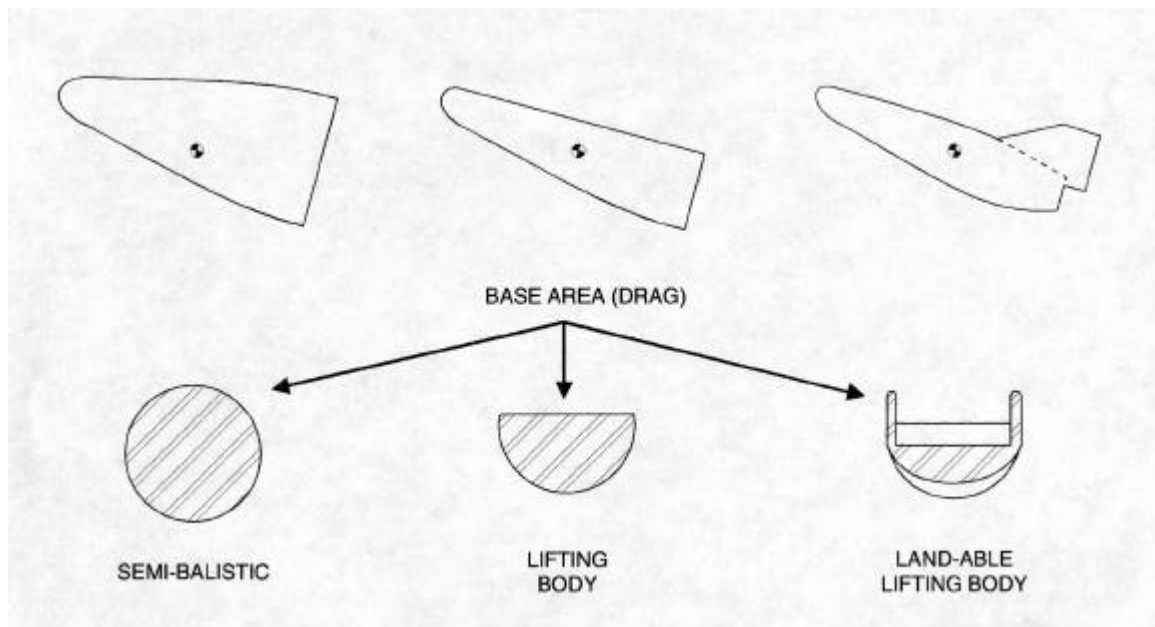
# Chapter 3

## The M2-F1 Program

The first attempt to actually fly and land an entry-configured lifting body occurred in April 1963. The flight occurred at NASA FRC at Edwards AFB. The vehicle was a small, light weight shape designated the M2-F1.

### 3.1 Theoretical Development

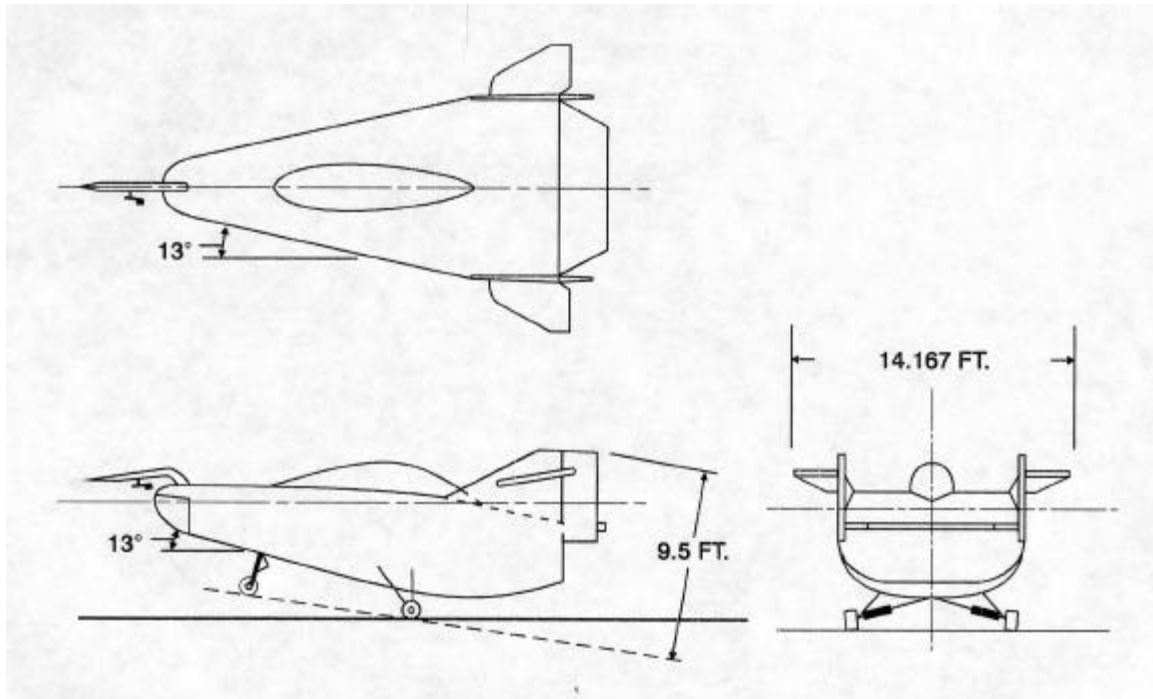
The M2 Lifting Body configuration was developed by Alfred J. Eggers, C.A. Syvertson, George Edwards, and George Kenyon at the NASA Ames Research Center (ARC). The approximate evolution of the design is shown in Figure 3-1.



**Figure 3-1: Evolution of M2 Lifting Body Design**

The design started with a blunted, 26-degree nose cone. With a vertically offset center of gravity to establish an angle of attack, a nose cone such as this could perform a semi-ballistic entry. The top half of the cone was flattened to provide additional lift and to reduce the base area and thus reduce drag. The base area was reduced even more by boat-tailing both the upper and lower surfaces of the half cone. The boat-tailing simultaneously improved the entry trim capability. Fins were added to provide directional stability and to add lift at low speed (Reference Syvertson, 1968). Preliminary low-speed wind tunnel tests indicated that this configuration should have a maximum  $L/D$  of about 3.5 and would probably be land-able if an adequate control system could be developed.

Robert D. "Dale" Reed was a research engineer at the NASA FRC (now Dryden Flight Research Center) at Edwards. He had been following the development of the lifting body shapes at Ames and Langley with some interest and wanted to develop a low-cost approach to assessing the land-ability of these shapes. Reed and Eggers began to develop an M2 configuration that would be suitable for a piloted experiment. They added small horizontal control surfaces or elevons outboard of the vertical fins (referred to as "elephant ears") to provide lateral control and lateral damping. A cockpit and windows in the nose provided visibility for the pilot during landing. This configuration was designated the M2-F1 (Figure 3-2).



**Figure 3-2: Three-View Drawing, M2-F1**

### **3.2 Technical and Physical Development**

Reed constructed a 24-inch radio-controlled model of the M2-F1 shape and towed it behind a larger radio-controlled model. He showed movies of these flights to NASA FRC Director Paul Bikle, and presented him a proposal to build a piloted, light-weight, low-cost version of the M2-F1. Reed envisioned a pathfinder program that would establish the feasibility of landing an entire class of lifting body vehicles. Both Reed and Bikle were active sailplane pilots (Bikle was an internationally known competition pilot), and thus both were familiar with glider landing techniques and also launching techniques. Bikle decided to proceed in September 1962. He appointed Reed to head a small team of research engineers (approximately six people). They designed a light weight vehicle that could be built in two segments: (1) an internal structure including the landing gear, flight controls, seat, and primary load carrying structure (Figure 3-3), and (2) a light-weight external shell in the shape of the M2-F1. Close and continuous coordination with personnel from NASA ARC continued throughout the design of the vehicle.



**Figure 3-3: Internal Structure of the M2-F1**

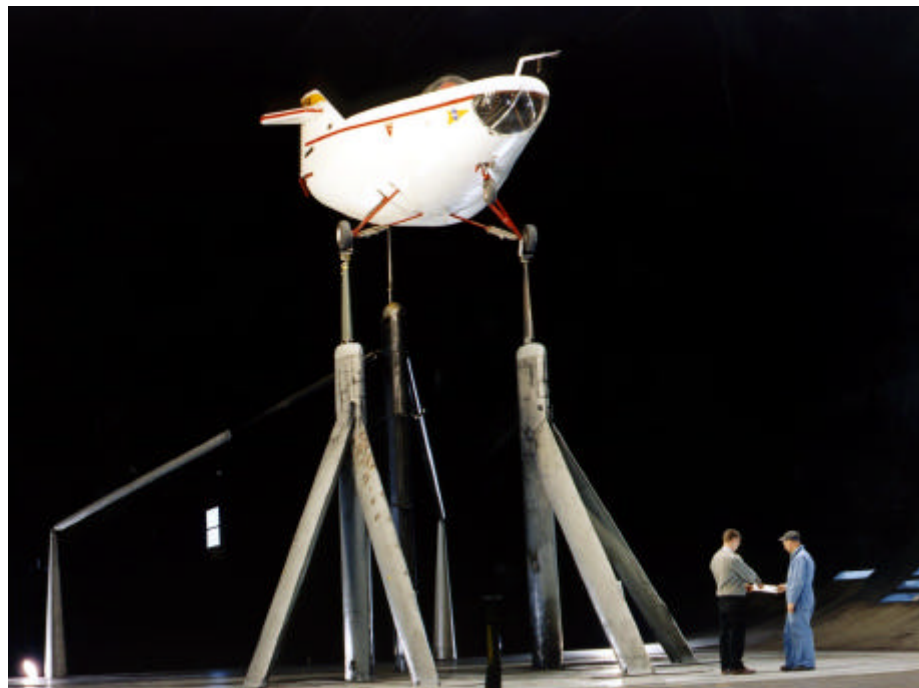
The control system was simple with designed-in flexibility for experimentation during the early flights. The pilot's control stick was connected to a "swash-plate" at the rear of the aircraft. There were four horizontally-hinged control surfaces (left and right elevons inboard of the fins, and left and right elevons outboard of the fins) and two vertically-hinged surfaces (left and right rudders on each fin). These surfaces could be connected to the "swash-plate" in several ways. This allowed various control surface combinations and stick gearing values for pitch and roll control to be tested by simply changing the connections at the "swash-plate." There was no stability augmentation in the M2-F1.

NASA FRC created an internal organization that was composed of Reed, the design engineering team of Richard Klein and Richard Eldredge, and eight skilled craftsmen in the NASA FRC shops (four machinists and four sheet metal workers), as well as test pilots and operations engineers from FRC's Flight Operations. The intent was to keep the contracted cost low so as to not incur the delays associated with high-level review and approval. Bikle thought that the M2-F1 shell should be constructed by someone familiar with glider construction methods. The contract for construction avoided reference to government specifications and documentation and thereby greatly reduced the cost. This cost-effective, hands-on approach maximized the use of skilled, in-house personnel and minimized the complexity of contracts and work statements for outside work. This modus operandi was used through the entire Lifting Body program.

### 3.3 Construction

The size of the M2-F1 was dictated by the desire to achieve a fairly light wing loading (approximately 9 lbs. per sq. ft.). This produced a vehicle that was 20 feet long with a base width (or span) of 9.5 feet. Under the direction of Dale Reed and his small team of design engineers, the NASA FRC shop personnel manufactured the internal structure. Simultaneously the construction of the external shell was contracted to Gus Briegleb, a sailplane designer who was operating a glider operation at nearby El Mirage airport at Adelanto, California. The shell was constructed at his shop by a team of about five workers including his two sons, Ross and Ken. The M2-F1 shell was constructed of plywood using methods typical of glider construction at that time. NASA gave Briegleb the necessary loft lines for the M2-F1 shape and also identified the shell attach-point dimensions and expected loads. The total contracted cost for the M2-F1 shell was approximately \$10,000. The shell was completed and delivered to NASA FRC. The final assembly of the shell and internal structure was completed at NASA FRC only four months after the go-ahead from Bikle.

Following ground checkout of the control system, the M2-F1 vehicle was trucked to the NASA Ames Research Facility at Moffett Field, California, where it was installed in the 40x80-foot full-scale wind tunnel (Figure 3-4).



**Figure 3-4: M2-F1 in Ames 40 X 80 Wind Tunnel**

A complete low-speed wind tunnel test series was performed. On many of the wind tunnel runs the assigned test pilot, Milt Thompson, was seated in the M2-F1 operating the controls while data measurements were being taken. Because of the low wing loading of the M2-F1 (9 psf), the airspeeds obtained in the wind tunnel were about the same as those expected in flight. The success of these tests was crucial to the continuation of the program. A removable, triangular center fin had been constructed in anticipation of low directional



stability, and tests were run with and without the fin. The results showed that the directional stability was adequate without the fin. Overall the wind tunnel results supported the potential flyability and land-ability of the vehicle. It was returned to Edwards to be prepared for flight ([Reference Horton, 1965](#)). A small solid landing rocket, referred to as the "instant L/D rocket," was installed in the rear base of the M2-F1. This rocket, which could be ignited by the pilot, provided about 250 pounds of thrust for about 10 seconds. The rocket could be used to extend the flight time near landing if needed.

Two standard methods for launching sailplanes are the car-tow and the air-tow. The NASA test team intended to use both methods for launching the M2-F1. Recognizing that the drag of the lifting body would be considerably higher than that of a sleek sailplane, NASA FRC procured a high performance Pontiac convertible and proceeded to have it modified to "race car" status in order to have the speed and power needed for the car tows. The convertible body style allowed engineers to observe the M2-F1 flights from aft-facing seats (Figure 3-5). Walter Whiteside, Assistant to the Chief of Operations at NASA FRC, became the crew chief and "tow-driver" of the Pontiac. Ralph Sparks maintained the car's high performance capability throughout the program.



**Figure 3-5: Pontiac Convertible Tow Vehicle**

Air-tows were accomplished behind a C-47 "Gooney Bird" cargo airplane, which NASA FRC maintained as a utility aircraft. A tow hook (of the type used during World War II for towing troop gliders) had been found in a junk yard and installed on the tow plane. A 1000-foot towline was used.

### **3.4 Flight Testing**

The M2-F1 flight test program ran from the early car tows in April 1963 to the last flights in August 1966. Seven pilots flew the vehicle.

#### **3.4.1 Car Tows**

Flight testing began with car tows on the smooth surface of Rogers dry lakebed at Edwards on 5 April 1963. NASA's Milt Thompson was at the controls of the M2-F1. The Pontiac towed the vehicle until it was airborne, then the pilot assessed the handling qualities of a particular control combination. Among the combinations tried were connecting the rudder to the lateral stick deflection and the pedals to the elevons. Differential upper flap deflections had been found to have low roll effectiveness in the full-scale tunnel so the left and right body flaps were linked together for pitch control only, then left that way for the entire test program. The most suitable system was a standard hookup with the lateral stick deflection moving the elevons, the rudder pedals operating the rudders, and the longitudinal stick moving both the body flap and pitch movement of the two elevons. When acceptable control was established, the tow speeds were increased until the vehicle could lift off and fly for several minutes behind the tow car, then release and land (Figure 3-6). Since the full-scale tunnel tests did not show any improvement in lateral stability or handling qualities with the center fin installed, the fin was never tried in actual flight. The small landing rocket was tested during taxi tests and was also operated while airborne during car tows.

About 93 car tows were performed before the first air tow was attempted. The car-tow technique was used throughout the program to evaluate any changes that were made to the vehicle or the control system and to check out new pilots. Nearly 400 car tows were accomplished during the course of the program.

#### **3.4.2 Air Tows**

Prior to the first air tow, an T-37 ejection seat replaced the simple, light-weight pilot seat that was used in the test vehicle for car tows. This gave the pilot a capability to eject safely from the M2-F1 from any portion of a flight including a zero-altitude, zero-speed condition. Thompson flew the first air tow on 16 August 1963. The flight was quite successful. It was followed by a series of test flights to determine the actual performance and stability characteristics of this unique aircraft (Figure 3-7).

Taking off from Rogers dry lakebed, the M2-F1 pilots maneuvered into a high tow position above the wake of the tow plane. The flights circled the edge of the lakebed during the climb to insure that the M2-F1 could reach a lakebed runway in the event of a rope break. When the tow plane reached an altitude between 8,000 and 11,000 feet above the lakebed, and was approximately over the intended landing site on the lakebed, the M2-F1 pilot would release from the tow plane and begin a steep gliding turn. He would initiate the landing flare about 300 feet above the ground and at a speed of about 110 knots. Because of the light wing loading, the M2-F1 lost speed very quickly. Only 8 seconds elapsed between the start of flare and touchdown at approximately 75 knots (Figure 3-8).



Figure 3-6: M2-F1 Low Speed Car Tow



Figure 3-7: M2-F1 Air Tow Behind C-47





**Figure 3-8: M2-F1 in Free Flight using "Instant L/D Rocket"**

### **3.4.3 Handling Qualities**

The M2-F1 in free flight had fairly good handling characteristics. Pitch control was positive and well damped. Steady state sideslips could be accomplished smoothly, although they required high pilot concentration.

The M2-F1 exhibited one unusual characteristic that required some learning and adapting by the pilots. It was brought about by the combination of sideslip produced by deflection of the ailerons, and of very high dihedral effect (a tendency to roll sharply when a small amount of sideslip is present). When the vehicle was commanded to roll, there was a slight hesitation brought about by a small sideslip. The vehicle would then begin to roll as originally commanded.<sup>1</sup> This characteristic was of little consequence during free flight of the M2-F1 when there was little requirement for quick response or for precise bank angle control. While on tow, however, the pilot's visibility was hampered by the small nose window. The poor visibility, coupled with a requirement to stay in position behind the tow plane, created a need for quick roll response. The use of a small amount of rudder for coordination was used by most pilots, however excessive rudder resulted in a tendency toward Pilot Induced Oscillation (PIO). Some pilots had difficulty adapting to this characteristic (See Paragraph 3.5.1).

During the flare maneuver just before landing, the wide upper deck of the M2-F1 and the extreme nose-high attitude of the vehicle caused the pilot to lose his view through the canopy of the ground and the horizon. He was forced to transfer his viewing to the small nose window. This hampered his depth perception and thus his ability to accurately control the landing sink rate. All M2-F1 pilots eventually learned to compensate for this difficulty. Other handling quality comments are contained in Appendix B.

---

<sup>1</sup> This characteristic is commonly referred to as "adverse yaw" in the aircraft community. It is a feature which designers strive to eliminate or minimize by altering the shape of the wings or ailerons.

#### 3.4.4 Schedule and Pilots

In the early 1960's the lifting body concepts were viewed as adversarial to the winged-entry concepts such as the X-15 and X-20. In fact, the lifting body supporters were at least partly responsible for the cancellation of the Dyna Soar program. They advocated the use of existing ablation technology rather than supporting the development of the exotic high-temperature materials required by the Dyna Soar. It was with some chagrin, therefore, that the winged-entry advocates viewed the M2-F1 vehicle flight test program growing out of the airplane community rather than the missile community, which had previously been their prime adversary. Test pilot Milt Thompson simultaneously supported the X-20 program while flying the early flights on the M2-F1. Flight research was viewed as advancing the technology of flight in any direction that seemed fruitful. This philosophy was typical of Bikle and others at NASA FRC at that time.

Colonel Chuck Yeager flew 33 car tows and five air tows in the M2-F1. At the time he was the Commandant of the Air Force Test Pilot School at Edwards AFB. Bikle had a high degree of respect for Yeager's abilities as an aviator and for his accurate reporting abilities as a test pilot. Bikle invited him to fly the M2-F1 to get his opinion as to the practicality of the concept. On 10 Dec 1963, shortly after his first successful air tow in the M2-F1, Yeager ejected from a rocket-assisted NF-104A and received severe facial burns. The M2-F1 was the first aircraft that Yeager flew following his month-and-a-half hospital recuperation (likened by some to a long stay in orbit). After his successful flights in the M2-F1 Yeager enthusiastically supported the lifting body venture.

In all, ten pilots flew approximately 395 M2-F1 car tows. Seven of the ten pilots flew an additional 77 air tows. (The M2-F1 schedule relative to the other lifting bodies is shown in [Figure 2-1](#). A summary log of flights and pilots is included in Appendix C.)

<u>Pilot</u>	<u>Number of Car Tows</u>	<u>Air Tows</u>
Milt Thompson	Unknown	46
Bruce Peterson	49	17
Major Don Sorlie	33	5
Captain Jerry Gentry	Unknown	2
Colonel Chuck Yeager	33	5
Don Mallick	32	2
Bill Dana	Unknown	1
Captain Joe Engle	3	0
Fred Haise	3	0
Major Jim Wood	10	0

### **3.5 Technology Lessons Learned**

The M2-F1 flight test program generated technical knowledge from accidents and lesser incidents as well as through improvements and problem resolutions. Some problems remained unresolved at the end of the program.

#### **3.5.1 Accidents/Incidents**

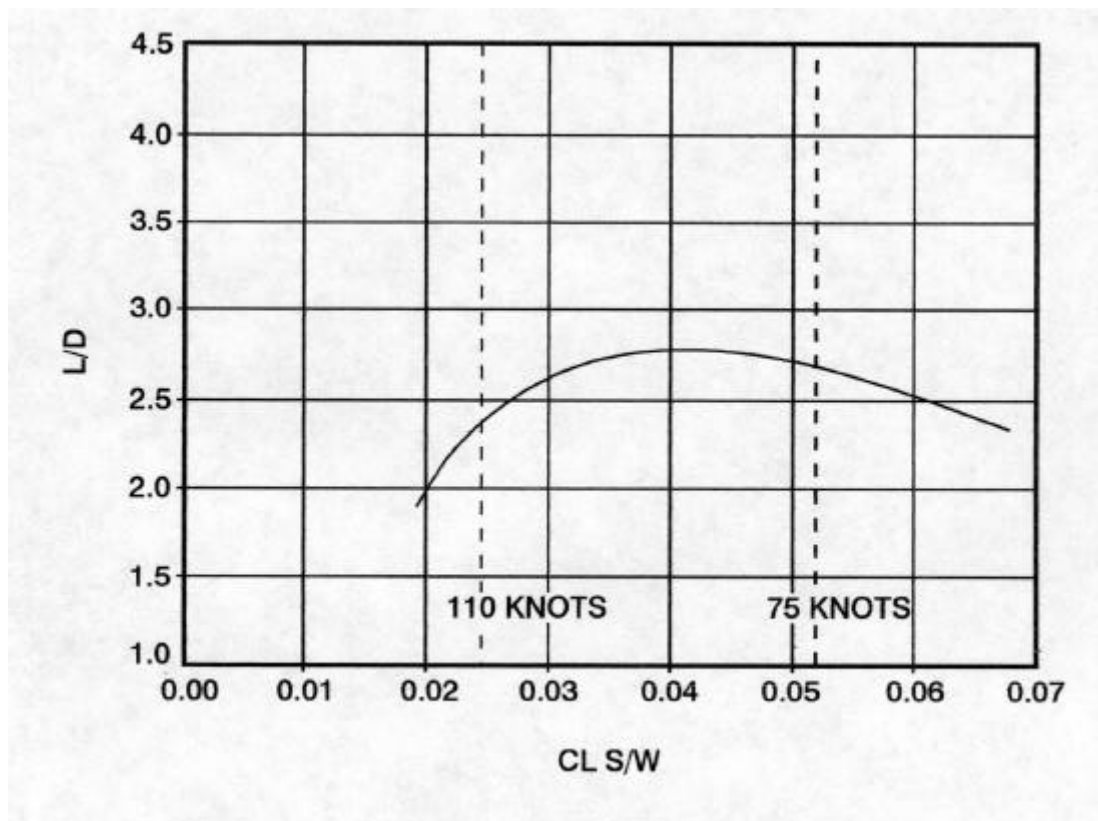
The M2-F1 landing gear was equipped with automotive shock struts serviced with heavy-weight oil. The system worked well during the early flights which were in warm weather. On a very cold morning in December 1963, pilot Bruce Peterson made a rather hard landing following an air tow. Both wheel axles failed due to the combination of the hard landing and shock struts stiffened by the cold temperature. Luckily both axles failed simultaneously so the vehicle settled abruptly onto the gear legs, but tracked straight ahead to a stop. The shock struts were subsequently replaced with elastic "bungee" cords and no further incidents of gear failure occurred.

The M2-F1 was still flying when the M2-F2 and HL-10 were delivered to NASA FRC (Figure 2-1). Near the end of the M2-F1 flight program the AF assigned test pilot Captain Jerauld Gentry to the Joint AF/NASA Lifting Body program in anticipation of delivery of the heavy weight vehicles. NASA agreed to a checkout flight for Gentry in the M2-F1. Shortly after takeoff behind the C-47 tow plane, and at an altitude of a mere 400 feet above the lakebed, the M2-F1 began to roll violently from side to side. The oscillations increased in magnitude until the vehicle was inverted. At this point, Gentry released from the tow line and completed the roll back to an upright position. He used the landing rocket after recovering from the roll to give him more time to accomplish the landing and he landed safely straight ahead on the lakebed. After a limited discussion and analysis it was concluded that the vehicle had been upset by the tow plane slipstream. After receiving some additional tow training in a sailplane, Gentry again tried an M2-F1 air tow. An identical incident occurred on the second attempt. It was generally concluded that the combination of poor forward visibility on tow (Gentry was shorter than the other M2-F1 pilots), known lag in the lateral responsiveness, and aggressive pilot actions had caused a classical pilot-induced oscillation (PIO) to occur. At this point Bickle grounded the M2-F1. Its primary mission accomplished, it was retired from further flight activity on 18 August 1966.

#### **3.5.2 Validations**

The M2-F1 program demonstrated the feasibility of the lifting body concept for horizontal landings of atmospheric entry vehicles. It also demonstrated a procurement and management concept for prototype flight test vehicles that produced rapid results at VERY low cost (approximately \$40,000 excluding salaries of Government employees assigned to the project).

In-flight measurements of Lift-to-Drag ratio were 10 percent higher than those measured on the same vehicle in the full-scale wind tunnel. The measured free-flight value of maximum L/D was 2.8 (Figure 3-9). Notice that both the full-scale tunnel results and the flight test results for L/D were considerably less than the value of 3.5 predicted with earlier and smaller wind tunnel models. The reason for the discrepancy was that the M2-F1 had a fixed landing gear and some canopy differences as well as some of the normal manufacturing joints and other protrusions associated with real flight vehicles.



**Figure 3-9: M2-F1 Trimmed Lift/Drag Ratio**

### 3.5.3 Problems Resolved

An acceptable (but not optimized) flight control system was developed during the early car tows and was used throughout the M2-F1 program. Even though this system was a simple mechanical control system, it produced acceptable handling qualities over most of the flight envelope. It demonstrated that an acceptable and practical control system for a lifting body vehicle was possible.

### 3.5.4 Unresolved Problems

In a foreboding of things to come, the M2-F1 exhibited some peculiar roll response characteristics resulting from adverse yaw and the very high roll-to-sideslip ratio of the highly swept conical shape.

Although successful landings were performed at very low values of L/D (less than 3.0), the wing loading of the M2-F1 was considerably lower than that of any of the proposed lifting body entry vehicles. The ability to land at the higher mission weight and resulting higher approach and landing speeds had yet to be demonstrated.

Forward visibility was considered to be marginal during air tows and was barely adequate during the actual landing at high angle of attack. This was in spite of a window placed in the nose area specifically for the landing maneuver. The requirement for a thick ablator on the nose of an actual entry vehicle would preclude the use of ANY forward window in this location for pilot visibility at landing. Periscopes or blow-off panels were being considered to solve this problem for future lifting body vehicles.

### **3.6 Test Sites**

All flights of the M2-F1 lifting body were conducted over, and landed on, Rogers dry lakebed at Edwards AFB, California. After the full-scale wind tunnel tests at Ames, the vehicle remained at NASA FRC and maintenance was accomplished in the Calibration Hangar (now building Number 4801). Tests of the solid rocket "instant L/D" motor were conducted on the ramp as well as on the lakebed during early taxi tests.

### **3.7 Current Status of Aircraft**

The M2-F1 vehicle remained at NASA FRC after its last flight in August 1966. It was displayed in an informal museum area in front of the main building for several years. The fabric and plywood structure deteriorated from the sun and weather. The vehicle was eventually donated to the Smithsonian Institution. In February 1994 a contract was let through NASA FRC to Dick Fischer (a former NASA FRC employee) for \$100,000 to begin restoration of the M2-F1. He has subcontracted much of the work to other NASA retirees who actually worked on the airplane during its construction and flight testing days. The restoration is expected to be completed in 1997. The location and method of final display of the M2-F1 has not yet been decided, but it is expected to remain at Edwards.

The Pontiac tow vehicle was turned over to the NASA Langley Research Center (LaRC), which used it to tow test devices for measuring tire/runway friction.